



INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(51) International Patent Classification 6 : A61F 2/06		A1	(11) International Publication Number: WO 99/47077 (43) International Publication Date: 23 September 1999 (23.09.99)
(21) International Application Number: PCT/US99/05813 (22) International Filing Date: 18 March 1999 (18.03.99)		(81) Designated States: AU, CA, JP, European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE).	
(30) Priority Data: 09/040,880 18 March 1998 (18.03.98) US		Published <i>With international search report.</i>	
(71) Applicant: MEADOX MEDICALS, INC. [US/US]; 45 Barbour Pond Drive, Wayne, NJ 07470 (US).			
(72) Inventors: GOLDS, Ellen; 424 Broadway, Hastings-on-Hudson, NY 10706 (US). LENTZ, David, J.; 1453 Caminito Batea, La Jolla, CA 92037 (US). HENDERSON, Jamie; 55 Truman Boulevard, Oakland, NJ 07436 (US). DORMIER, Edward; 17 Lea Place, Rockaway, NJ 07886 (US). ZDRAHALA, Richard, J.; 9461 Yukon Avenue South, Bloomington, MN 55438 (US).			
(74) Agents: ABBRUZZESE, Salvatore, J. et al.; Hoffmann & Baron, LLP, 6900 Jericho Turnpike, Syosset, NY 11791 (US).			
(54) Title: IMPROVED PTFE VASCULAR PROSTHESIS AND METHOD OF MANUFACTURE			
(57) Abstract			
<p>An implantable microporous ePTFE tubular vascular graft exhibits long term patency, superior radial tensile strength and suture hole elongation resistance. The graft includes a first ePTFE tube and a second ePTFE tube circumferentially disposed over the first tube. The first ePTFE tube exhibits a porosity sufficient to promote cell endothelization tissue ingrowth and healing. The second ePTFE tube exhibits enhanced radial strength in excess of the radial tensile strength of the first tube. The stent provides patency to the endoprosthesis.</p>			

FOR THE PURPOSES OF INFORMATION ONLY

Codes used to identify States party to the PCT on the front pages of pamphlets publishing international applications under the PCT.

AL	Albania	ES	Spain	LS	Lesotho	SI	Slovenia
AM	Armenia	FI	Finland	LT	Lithuania	SK	Slovakia
AT	Austria	FR	France	LU	Luxembourg	SN	Senegal
AU	Australia	GA	Gabon	LV	Latvia	SZ	Swaziland
AZ	Azerbaijan	GB	United Kingdom	MC	Monaco	TD	Chad
BA	Bosnia and Herzegovina	GE	Georgia	MD	Republic of Moldova	TG	Togo
BB	Barbados	GH	Ghana	MG	Madagascar	TJ	Tajikistan
BE	Belgium	GN	Guinea	MK	The former Yugoslav Republic of Macedonia	TM	Turkmenistan
BF	Burkina Faso	GR	Greece	ML	Mali	TR	Turkey
BG	Bulgaria	HU	Hungary	MN	Mongolia	TT	Trinidad and Tobago
BJ	Benin	IE	Ireland	MR	Mauritania	UA	Ukraine
BR	Brazil	IL	Israel	MW	Malawi	UG	Uganda
BY	Belarus	IS	Iceland	MX	Mexico	US	United States of America
CA	Canada	IT	Italy	NE	Niger	UZ	Uzbekistan
CF	Central African Republic	JP	Japan	NL	Netherlands	VN	Viet Nam
CG	Congo	KE	Kenya	NO	Norway	YU	Yugoslavia
CH	Switzerland	KG	Kyrgyzstan	NZ	New Zealand	ZW	Zimbabwe
CI	Côte d'Ivoire	KP	Democratic People's Republic of Korea	PL	Poland		
CM	Cameroon	KR	Republic of Korea	PT	Portugal		
CN	China	KZ	Kazakhstan	RO	Romania		
CU	Cuba	LC	Saint Lucia	RU	Russian Federation		
CZ	Czech Republic	LI	Liechtenstein	SD	Sudan		
DE	Germany	LK	Sri Lanka	SE	Sweden		
DK	Denmark	LR	Liberia	SG	Singapore		

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/05813

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 689 805 A (PINCHUK LEONARD) 3 January 1996 see abstract see column 3, line 35 - line 37 see column 7, line 7 - line 11; claim 15; figure 1 ----	1,2,4,7, 13,14
P,X	WO 98 26731 A (atrium MEDICAL CORP) 25 June 1998 see page 15, line 16 - line 29; claims 1,13; figures 2B,11 -----	1-3, 8-11,13

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 99/05813

Patent document cited in search report	Publication date	Patent family member(s)			Publication date
WO 9505132	A 23-02-1995	US 5735892 A			07-04-1998
		AU 6824994 A			14-03-1995
		CA 2167944 A			23-02-1995
		EP 0714269 A			05-06-1996
		JP 9501584 T			18-02-1997
		US 5700285 A			23-12-1997
		US 5810870 A			22-09-1998
US 4704130	A 03-11-1987	AT 92740 T			15-08-1993
		AU 600681 B			23-08-1990
		AU 6414986 A			30-04-1987
		CA 1322834 A			12-10-1993
		DE 3688873 A			16-09-1993
		DE 3688873 T			10-03-1994
		EP 0223415 A			27-05-1987
		JP 2065134 C			24-06-1996
		JP 7098057 B			25-10-1995
		JP 62161375 A			17-07-1987
		US 4813966 A			21-03-1989
US 5123917	A 23-06-1992	NONE			
EP 0689805	A 03-01-1996	CA 2152662 A			28-12-1995
		JP 8038519 A			13-02-1996
		US 5755774 A			26-05-1998
WO 9826731	A 25-06-1998	US 5897587 A			27-04-1999
		US 5824050 A			20-10-1998
		AU 5898498 A			15-07-1998

FIG. 6

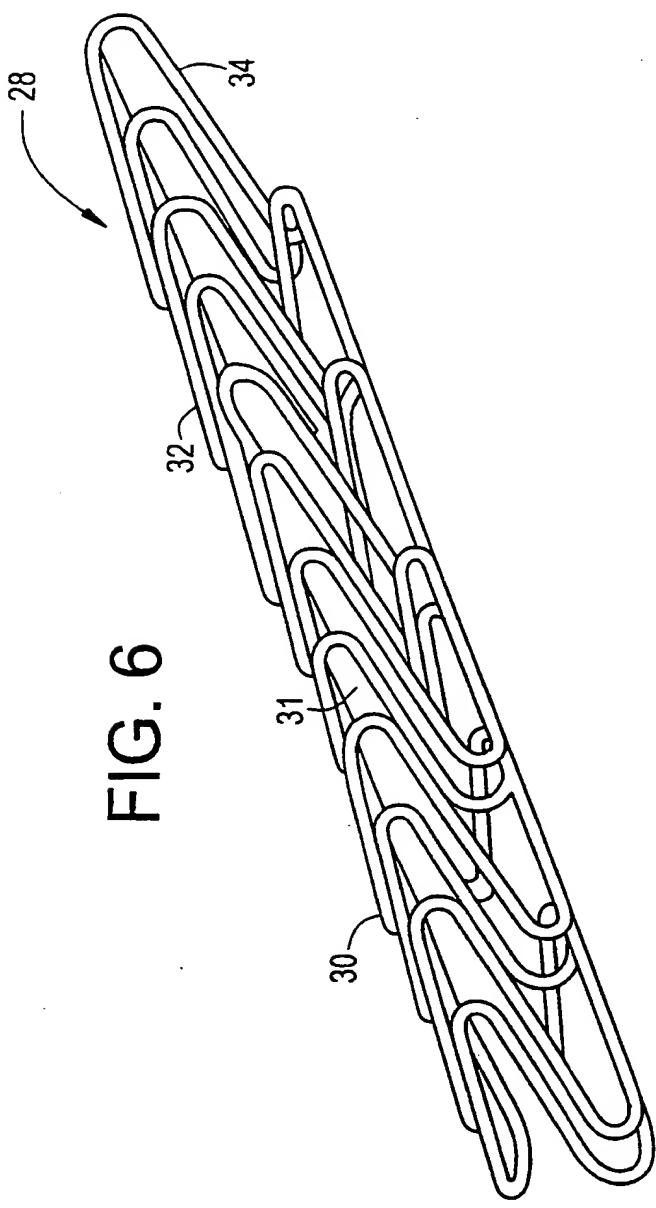


FIG. 8

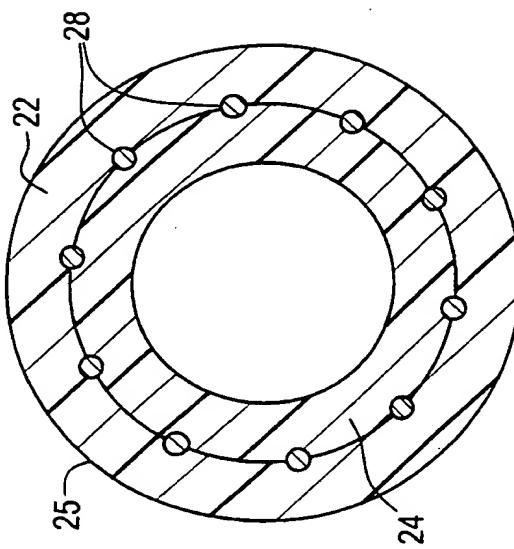
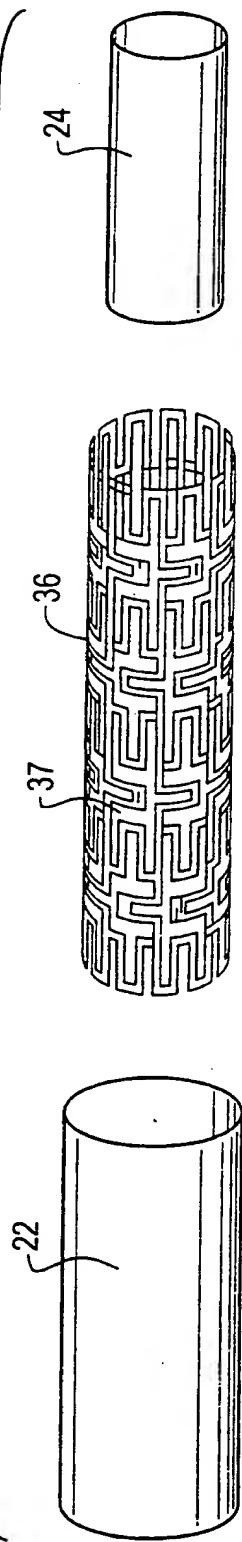


FIG. 7



INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 99/05813A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 A61F2/06

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 A61F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 95 05132 A (GORE & ASS) 23 February 1995 see page 4, line 2 - line 21 see page 12, line 22 - page 13, line 27; claim 45 ---	1-14
A	US 4 704 130 A (REED ANDREW M ET AL) 3 November 1987 see column 9, line 55 - column 10, line 2 ---	1
A	US 5 123 917 A (LEE PETER Y) 23 June 1992 see column 4, line 49 - column 5, line 7; claim 6; figure 1 ---	1,4 -/-

 Further documents are listed in the continuation of box C. Patent family members are listed in annex.

Special categories of cited documents:

- "A" document defining the general state of the art which is not considered to be of particular relevance
- "E" earlier document but published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search

Date of mailing of the international search report

25 June 1999

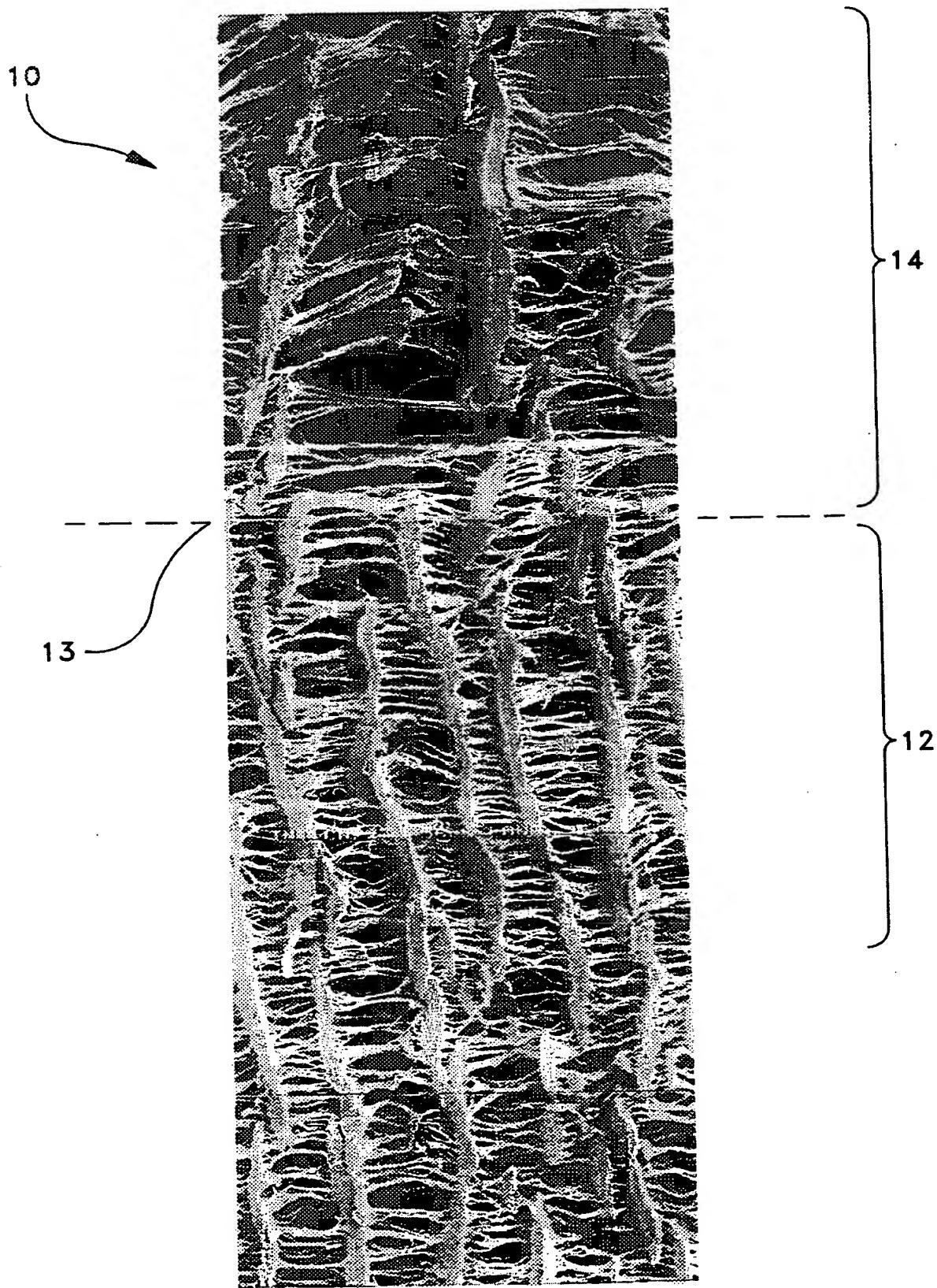
05/07/1999

Name and mailing address of the ISA
European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Stach, R

FIG.3



SUBSTITUTE SHEET (RULE 26)

3/4

FIG-4

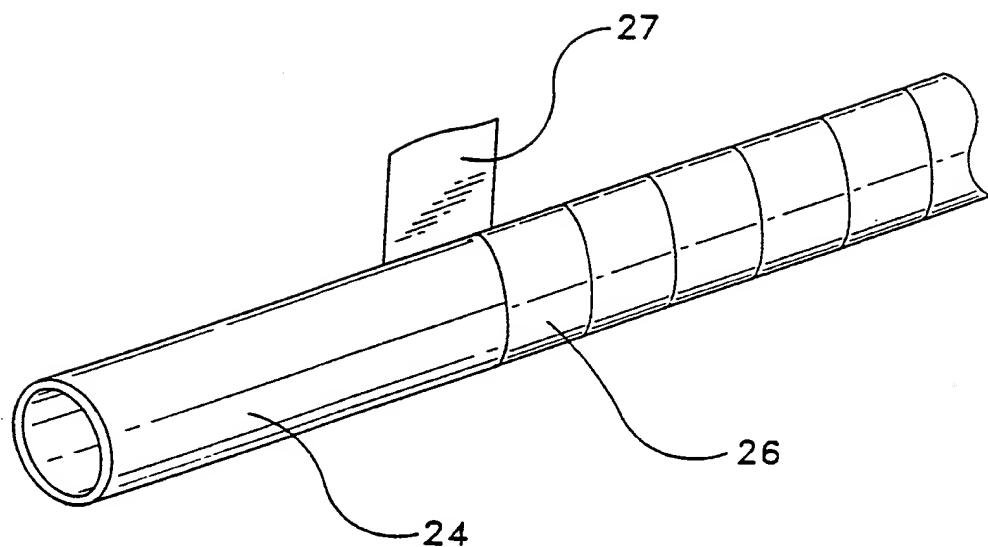
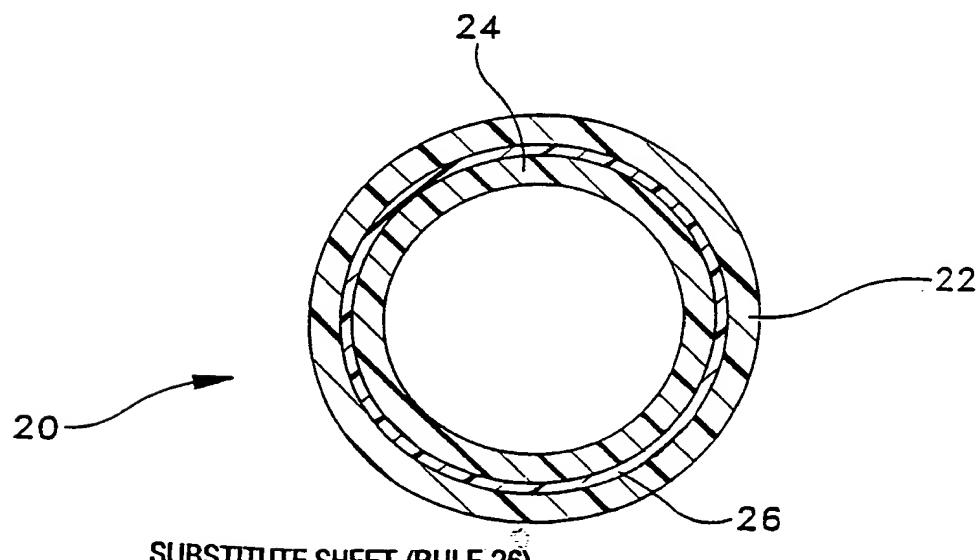


FIG-5



SUBSTITUTE SHEET (RULE 26)

said second PTFE tubular structure is adheringly secured to said outer tubular surface of said stent.

14. A tubular prosthesis according to claim 13 wherein said first and second PTFE tubular structures are adhesively secured to said inner and outer tubular stent surface by an adhesive.

1/4

FIG-1

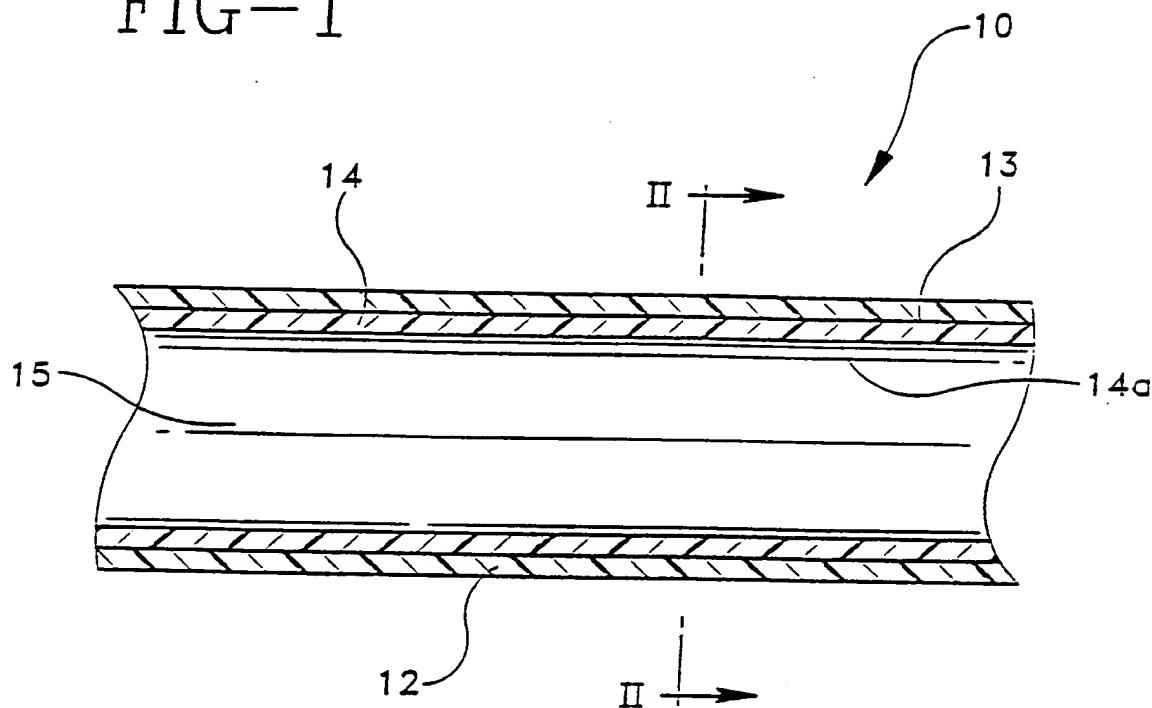
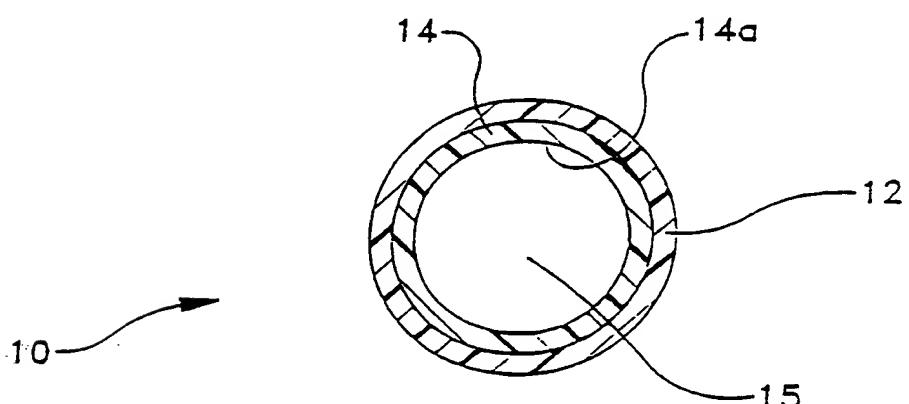


FIG-2



SUBSTITUTE SHEET (RULE 26)

WHAT IS CLAIMED IS:

1. A tubular intraluminal prosthesis comprising:
 - a first PTFE tubular structure having a first porosity;
 - a second PTFE tubular structure having a second porosity less than said first porosity, said second PTFE tubular structure being disposed externally about said first PTFE tubular structure to define a distinct porosity change between said first and second PTFE tubular structure; and
 - a tubular diametrically deformable stent interposed between said first and second PTFE tubular structure.
2. A tubular prosthesis of claim 1 wherein said stent defines a tubular wall having a plurality of open spaces therethrough.
3. A tubular prosthesis of claim 2 wherein said first PTFE tubular structure is adheringly secured to said second PTFE tubular structure through said open spaces of said interposed stent.
4. A tubular prosthesis of claim 2 wherein said tubular wall of said stent includes opposed inner and outer tubular surfaces and wherein said first PTFE tubular structure is adheringly secured to said inner tubular surface of said stent and said second PTFE tubular structure is adheringly secured to said outer tubular surface of said stent.
5. A tubular prosthesis of claim 3 wherein said first PTFE tubular structure is laminated to said second PTFE tubular structure through said open spaces of said interposed stent.
6. A tubular prosthesis of claim 3 wherein said first PTFE tubular structure is adhesively secured to said second PTFE tubular structure through said open spaces of said interposed stent.

7. A tubular prosthesis of claim 4 wherein said first and second PTFE tubular structures are adheringly secured to said inner and outer tubular stent surface by an adhesive.
8. A method of making a tubular intraluminal prosthesis comprising the steps of:
 - providing a first tubular structure having a first porosity, consisting of an interior and exterior surface;
 - placing a tubular diametrically deformable stent circumferentially around the exterior surface of said first tubular structure;
 - disposing a second PTFE tubular structure externally about said tubular diametrically deformable stent, said second PTFE tubular structure having a second porosity less than said first porosity, and defining a distinct porosity change between said first and second PTFE tubular structures.
9. A method of making a tubular intraluminal prosthesis according to claim 8 wherein said stent defines a tubular wall having a plurality of open spaces therethrough.
10. A method of making a tubular intraluminal prosthesis according to claim 9 wherein said first PTFE tubular structure is adheringly secured to said second PTFE tubular structure through said open spaces of said stent.
11. A method of making a tubular prosthesis according to claim 10 wherein said first PTFE tubular structure is laminated to said second PTFE tubular structure through said open spaces of said stent.
12. A method of making a tubular prosthesis according to claim 10 wherein said first PTFE tubular structure is adhesively secured to said second PTFE tubular structure through said open spaces of said stent.
13. A method of making a tubular prosthesis according to claim 8 wherein said tubular wall of said stent includes opposed inner and outer tubular surfaces and wherein said first PTFE tubular structure is adheringly secured to said inner tubular surface of said stent and

may be of the self-expanding type which expands upon implantation. Such a stent may be formed of a temperature sensing expanding metal such as nitinol.

Although a wide variety of different stents may be used, Figure 6 shows a perspective view of one particular stent which may be employed between outer tube 22 and inner tube 24.

5 The particular stent shown in Figure 7 is more fully described in commonly assigned U.S. Patent No. 5,575,816 to Rudnick, et al. Stent 28 is an intraluminally implantable stent formed of helically wound wire. Multiple windings 30 of a single metallic wire 32 provide stent 28 with a generally elongate tubular configuration which is radially expandable after implantation in a body vessel. The multiple windings 30 of stent 28 define open spaces 31 through the tubular configuration. Stent 28 further defines a central open passage 34 through the tubular configuration.

10 Referring to Figure 7, an exploded view of a stent/graft composite device 25 is shown. Composite device 25 includes an outer tube 22 and inner tube 24 with a stent 36 positioned therebetween. The stent 36 shown in Figure 7 may be the type more fully 15 described in U.S., Patent No. 4,733,665, and is an example of another stent configuration which may be employed in the composite stent/graft medical device 25.

20 Stent 36 is an expandable and deformable tubular structure comprised of longitudinally extending parallel slots 37. The slots define open spaces through the tube. The stent not only ensures patency and flexibility with the slotted configuration, but the open spaces allow adhering of the two tubular layers through the plurality of slots in the stent.

Figure 8 shows a cross-section of a similar stent/graft composite device where the stent 28 of Figure 6 is interposed between inner tube 24 and outer tube 22.

25 While two types of stents are shown herein it is contemplated that a number of different stents may be used in the composite device with one or more inner and outer tubular layers.

In order to make such a composite vascular endoprosthesis, a thin extruded ePTFE tube is taken and expanded over a stainless steel mandrel. The tube 24 is then expanded and sintered in a manner described above. This forms inner tube 24. Stent 28 is then placed over the first tube.

5 The combination inner tube 24 and stent 28 on the mandrel may then be used as another mandrel over which the outer tubular layer is formed. The inner diameter of the outer tubular layer is selected so that it may be easily but tightly be disposed over the outer diameter of the inner tube and stent. The outer tube 21 may be expanded and sintered in a manner described above.

10 Adhesive may be used to adhere the stent to the inner tube, the outer tube, or both. Alternatively, the stent may be adhered to the inner and outer tubular layers without the use of an adhesive.

15 When a stent with a plurality of open spaces or slots therethrough, such as slotted stent 36 or wire stent 28, is utilized in the stent/graft composite device 25, the inner and outer tubular layers may be adhered to each other through the spaces in the stent. Such adherence may be accomplished with the use of an adhesive. Alternatively, the tubular layers may be adhered directly together through the spaces by lamination of the layers. Sintering is one method of effecting such adherence.

20 Various changes to the foregoing described and shown structures would now be evident to those skilled in the art. Accordingly, the particularly disclosed scope of the invention is set forth in the following claims.

EXAMPLE II

A thin extruded tube having wall thickness of 0.41 mm and an inner diameter of 6.2 mm was expanded over a stainless steel mandrel at 500°F to 700% elongation. The ePTFE tube was then sintered at 660°F for 14 minutes, cooled, and removed from the oven. A 5 second thin extruded tube having wall thickness of 0.45 mm and an inner diameter of 6.9 mm was expanded over the first tube at 500°F and 400% elongation. The composite was sintered at 660°F for 14 minutes, cooled, and removed from the oven. The resultant composite tube had a wall thickness of 0.67 mm and an inner diameter of 5.8 mm.

Table I presents physical property data for a vascular graft of the type depicted in Example I described above. The composite graft was removed from the mandrel and subjected to standard testing of radial tensile strength and suture hole elongation. The radial strength of the 900%/400% composite graft is equivalent to a single layer 400% elongation graft and substantially stronger than a single layer 900% elongation graft, despite an overall thinner wall dimension. Additionally, the superior strength of the composite graft is demonstrated by the higher elongation capable of being borne by the graft prior to failure. The lower suture hole elongation, indicative of a smaller tear being caused by suturing and tensioning at a fixed value of 100 grams is clearly demonstrated for the graft prepared by the method of the current invention.

TABLE I

20	Physical Property Measurement	400% Elongation Single Layer Graft	900%/400% Elongation Composite Graft	900% Elongation Single Layer Graft
	Radial Tensile Strength (kg/mm ²)	0.48	0.48	0.2
25	Radial Strain at Break (%)	550	690	531
	Suture Hole Elongation (%)	87	81	158
	Wall Thickness	0.72	0.65	0.73

Referring now to Figures 4 and 5, a further embodiment of the present invention is shown. Tubular graft 20 is a composite structure similar to graft 10 described above. Graft 20 includes an outer tube 22 and an inner tube 24 formed generally in the manner described above. In order to further control the porosity and strength of the graft 20, especially at the 5 interface between outer tube 22 and inner tube 24, an additional layer may be employed in combination with outer tube 22 and inner tube 24.

As specifically shown in Figures 4 and 5, an additional layer 26 may be employed between inner tube 24 and outer tube 22. Layer 26 may include a helical wrap of ePTFE tape 27 placed over inner tube 24. The additional layer 26, however, may also exist as a sheet, 10 film, yarn, monofilament or multi filament wrap, or additional tube. The additional layer 26 may consist of PTFE, FEP, or other suitable polymer composition to obtain the desired performance characteristics. Layer 26 may be used to impart enhanced properties of porosity and/or strength to the composite graft 20. For example, an additional layer 26 of ePTFE tape 27 having a low IND and wrapped orthogonally to the length direction of graft 20 would 15 increase the radial strength of the resultant composite graft. Similarly, a layer of ePTFE having a high IND would increase the porosity of the composite structure thereby further promoting cell endothelization and/or tissue ingrowth.

As shown in Figure 4, layer 26 is disposed between inner tube 24 and outer tube 22, and functions as an intermediate layer therein between. It is further contemplated that the 20 additional layer may be employed over outer tube 22, or an additional layer may be used both over outer tube 22 and over inner tube 24.

With further reference to Figures 6-8, a further preferred embodiment of the present invention contemplates placing a stent between the inner tube 24 and outer tube 22, instead of intermediate layer 26 (Fig. 4) so as to form a stent/graft composite device 25. Several 25 advantages exist in employing such a stent/graft composite. The stent provides the prosthesis with significant strength, and ensures patency of the vessel. Furthermore, the stent permits endoluminal dilution as it expands radially outward once implanted. Such expansion is usually accomplished by an expandable balloon of a delivery device. Alternatively, the stent

An electron micrograph of such a structure produced according to the present invention is shown in Figure 3. The disparate IND's between the inner tube 14 and outer tube 12 are clearly evident, along with the step change in IND at the interface 13 between the inner tube 14 and outer tube 12. In this example, the strength of the interface 13 has been 5 established by the processing conditions described below to fully adhere the inner tube 14 and outer tube together, hence preventing relative motion and providing enhanced strength.

Graft 10 of the present invention may be formed by expanding a thin wall inner tube 14 at a relatively high degree of elongation, on the order of approximately between 400 and 2000% elongation preferably from about between 700% and 900%. Tube 14 is expanded 10 over a cylindrical mandrel (not shown), such as a stainless steel mandrel at a temperature of between room temperature and 645°F, preferably about 500°F. Tube 14 is preferably but not necessarily fully sintered after expansion. Sintering is typically accomplished at a temperature of between 645°F and 800°F preferably at about 660°F and for a time of between about 5 minutes to 30 minutes, preferably about 15 minutes. The combination of the 15 ePTFE tube 14 over the mandrel is then employed as a second mandrel, over which outer tube 12 is expanded. The ID of the outer tube 12 is selected so that it may be easily but tightly disposed over the OD of inner tube 14. The composite structure 10 is then sintered at preferably similar parameters. The level of elongation of outer tube 12 is lower than that of inner tube 14, approximately between 200% and 500% elongation preferably about 400%. 20 The expansion and sintering of outer tube 12 over the inner tube 14 serves to adheringly bond the interface 13 between the two tubes, resulting in a single composite structure 10.

As shown in Figure 3, the resulting composite structure has an inner surface defined by inner tube 14 which exhibits an IND of between 40 and 100 microns, spanned by moderate number of fibrils. Such microporous structure is sufficiently large so as to promote enhanced cell endothelization once blood flow is established through graft 10. Such cell endothelization enhances the long term patency of the graft.

The outer structure, defined by outer tube 12, has a smaller microporous structure, with IND of 15-35 microns and a substantial fibril density. Such outer structure results in an

increase in the strength of the outer tube, and hence of the composite structure. Importantly, the outer surface defined by the outer tube 12 exhibits enhanced suture retention due to the smaller IND.

Furthermore, the resulting composite structure exhibits a sharp porosity change
5 between the outer tube 12 and inner tube 14. This sharp porosity transition is achieved by providing an inner tube 14 having generally a given uniform porosity therealong and then providing a separate outer tube 14 having a resultant different porosity uniformly therealong. Thus a distinct porosity change is exhibited on either side of the interface 13 defined between inner tube 14 and outer tube 12.

10 In addition, the forming process described above results in a bonded interface between inner tube 14 and outer tube 12. The interface exhibits sufficient interfacial strength resulting from the direct sintering of the outer tube 12 over the inner tube 14 so as to assure complete bonding of the two tubes. The strength of the interface between the two tubes may be independently varied through selection of processing conditions and relative dimensions of
15 precursor extruded tubes 12 and 14 as desired to yield a range of performance.

The following examples serve to provide further appreciation of the invention but are not meant in any way to restrict the scope of the invention.

EXAMPLE I

A thin extruded tube having wall thickness of 0.41 mm and an inner diameter of 6.2
20 mm was expanded over a stainless steel mandrel at 500°F to 900% elongation. The ePTFE tube was then sintered at 660°F for 14 minutes, cooled, and removed from the oven. A second thin extruded tube having wall thickness of 0.45 mm and an inner diameter of 6.9 mm was expanded over the first tube/mandrel combination at 500°F and 400% elongation. The composite was then sintered at 660°F for 14 minutes, cooled and removed from the oven.
25 The resultant composite tube had a wall thickness of 0.65 mm and ID of 5.8 mm.

Figure 2 is a longitudinal cross-section of an alternate embodiment of the present invention producing a multi-layer ePTFE vascular graft.

Figure 3 is a scanning electron micrograph showing a cross-sectional view of a vascular graft produced using the present invention.

5 Figure 4 is a perspective showing of one of the tubular structures of the graft of Figure 1 over-wrapped with a layer of ePTFE tape.

Figure 5 is a cross-sectional showing of a further embodiment of the ePTFE vascular graft of the present invention.

10 Figure 6 is a perspective showing a stent which may be used in a composite stent/graft structure of the present invention.

Figure 7 is an exploded view of the composite stent/graft of the present invention.

Figure 8 is a cross-sectional showing of the stent/graft of figure 7.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS:

15 The prosthesis of the preferred embodiments of the present invention is a multi-layered tubular structure which is particularly suited for use as an endoprosthesis or vascular graft. The prosthesis is formed of extruded polytetrafluoroethylene (PTFE) as PTFE exhibits superior biocompatibility. Further, PTFE is particularly suitable for vascular applications as it exhibits low thrombogenicity. Tubes formed of extruded PTFE may be expanded to form ePTFE tubes where the ePTFE tubes have a fibrous state which is defined by elongated fibrils 20 interconnected by spaced apart nodes. Such tubes are said to have a microporous structure, the porosity of which is determined by the distance between the surfaces of the nodes, referred to as the internodal distance (IND). Tubes having a large IND (greater than 40 microns) generally exhibit long term patency as the larger pores promote cell endothelialization

along the inner blood contacting surface. Tubes having lower IND (less than 40 microns) exhibit inferior healing characteristics, however they offer superior radial tensile and suture retention strengths desirable in a vascular graft. The present invention provides a composite tubular structure which promotes long term patency of the graft by providing for enhanced 5 cell endothelization along the inner surface while exhibiting enhanced strength due to the presence of the outer layer.

Referring to Figures 1 and 2 of the drawings, composite graft 10 of the present invention is shown. Graft 10 is a elongate tubular structure formed of PTFE. Graft 10 includes a pair of coaxially disposed ePTFE tubes 12 and 14, tube 12 being the outer tube and 10 tube 14 being the inner tube. A central lumen 15 extends through composite graft 10, defined further by the inner wall 14a of inner tube 14, which permits the passage of blood through graft 10 once the graft is properly implanted in the vascular system.

Each tube 12 and 14 may be formed in a separate extrusion process. The process for the paste extrusion of PTFE tubes is well known in the extrusion art. Once extruded, the 15 tubes are expanded to form ePTFE tubes. As will be described hereinbelow, the tubes are expanded using differing process parameters (rates, deformation levels, temperatures, etc) to develop the desired microporous structures. The specifically designed structure of the resulting composite tube has defined properties of strength and porosity which yield a graft 10 having long term patency and good healing characteristics as well as superior strength 20 characteristics.

The present invention is designed to produce grafts with substantially different node/fibril structures with respect to the internal and external portions of the graft which are adjacent to the internal and external graft surfaces. As an example, the inner tube 14 is designed to have relatively high IND while the outer tube 12 is designed to have a lower IND. 25 Further, a distinct porosity change is clearly defined at the interface 13 between tubes 12 and 14. The inner tube 14 having a higher IND to allow enhanced cell endothelization, while the outer tube 12 having a lower IND provides superior strength to the overall composite.

is generally inserted in a radially compressed state and expanded either through a self-expanding mechanism, or through the use of balloon catheters.

A stent may be used in combination with a graft. Such a composite medical device would provide additional support for blood flow through weakened sections of a blood vessel. In endovascular applications the use of stent/graft combinations is becoming increasingly important because the combination not only effectively allows the passage of blood therethrough, but also ensures the implant will remain open.

As may be appreciated with stent/graft configurations, expansion and contraction of the stent exerts a radially tensile force against the graft structure supported thereon. This outward force maintains the stent/graft configuration open once implanted so as to assure patency of the vessel. Where the graft is found having a large IND which enhances tissue ingrowth and cell endothelization, such a graft structure may not possess sufficient strength to retain the expanded stent.

It is therefore desirable to provide an ePTFE vascular graft/stent which exhibits increased porosity especially at the inner surface thereof while retaining a high degree of radial strength especially at the external surface thereof in order to retain the expandable stent.

SUMMARY OF THE INVENTION:

It is an object of the present invention to provide an improved ePTFE vascular stent/graft combination.

It is a further object of the present invention to provide a ePTFE vascular stent/graft exhibiting an enhanced microporous structure while retaining superior radial strength provided by a stent, and an outer tear-resistant layer.

It is a still further object of the present invention to provide an ePTFE tubular structure having an inner portion exhibiting enhanced porosity and an outer portion exhibiting enhanced radial tensile strength and suture elongation characteristics.

It is yet another object of the present invention to provide a multi-layered ePTFE tubular vascular stent/graft composite having an inner ePTFE layer which has a porosity sufficient to promote cell endothelization, an intermediate stent layer exhibiting enhanced support strength to maintain patency, and an outer ePTFE layer with enough radial tensile strength to be tear resistant and compatible with said intermediate and inner layer.

In the efficient attainment of these and other objects, the present invention provides a tubular intraluminal prosthesis comprised of a first PTFE tubular structure having a first porosity, a second PTFE tubular structure having a second porosity. The first porosity of said first tubular structure is greater than the second porosity of said second tubular structure. The second PTFE tubular structure is positioned externally about the first PTFE tubular structure. A tubular diametrically deformable stent is interposed between the first and second PTFE tubular structure.

A method of making the tubular intraluminal prosthesis is also disclosed, which comprises the steps of providing a first tubular structure possessing a first porosity, placing a tubular diametrically deformable stent circumferentially around the exterior surface of the first tubular structure, then disposing a second PTFE tubular structure externally about the stent. The second tubular structure should possess a second porosity, such that the first porosity of the first tubular structure is greater than the second porosity of the second tubular structure, and a distinct porosity change between the first and second tubular structures should exist.

25 BRIEF DESCRIPTION OF THE DRAWINGS:

Figure 1 is a schematic longitudinal cross-section of a multi-layer ePTFE vascular graft of the present invention.

IMPROVED PTFE VASCULAR PROSTHESIS AND METHOD OF MANUFACTURE

FIELD OF INVENTION:

The present invention relates generally to a tubular implantable prosthesis formed of porous polytetrafluoroethylene. More particularly, the present invention relates to a multi-layered graft/stent endoprosthesis formed of a combination of expanded 5 polytetrafluoroethylene, and a tubular diametrically deformable stent.

BACKGROUND OF THE INVENTION:

It is well known to use extruded tubes of polytetrafluoroethylene (PTFE) as implantable intraluminal prosthesis, particularly vascular grafts. PTFE is particularly suitable as an implantable prosthesis as it exhibits superior biocompatibility. PTFE tubes may be 10 used as vascular grafts in the replacement or repair of a blood vessel as PTFE exhibits low thrombogenicity. In vascular applications, the grafts are manufactured from expanded polytetrafluoroethylene (ePTFE) tubes. These tubes have a microporous structure which allows natural tissue ingrowth and cell endothelization once implanted in the vascular system. This contributes to long term healing and patency of the graft.

15 Grafts formed of ePTFE have a fibrous state which is defined by interspaced nodes interconnected by elongated fibrils. The spaces between the node surfaces that is spanned by the fibrils is defined as the internodal distance (IND). A graft having a large IND enhances tissue ingrowth and cell endothelization as the graft is inherently more porous.

The porosity of an ePTFE vascular graft can be controlled by controlling the IND of 20 the microporous structure of the tube. An increase in the IND within a given structure results in enhanced tissue ingrowth as well as cell endothelization along the inner surface thereof. However, such increase in the porosity of the tubular structure also results in reducing the

overall radial tensile strength of the tube as well as reducing the ability for the graft to retain a suture placed therein during implantation. Also, such microporous tubular structures tend to exhibit low axial tear strength, so that a small tear or nick will tend to propagate along the length of the tube.

5 Attempts to increase the radial tensile, as well as axial tear strength of a microporous ePTFE tube include forming the tubular graft of multiple layers placed over one another. Examples of multi-layered ePTFE tubular structures useful as implantable prostheses are shown in U. S. Patent Nos. 4,816,338; 4,478,898 and 5,001,276. Other examples of multi-layered structures are shown in Japanese Patent Publication nos. 6-343,688 and 0-022,792.

10 While each of the above enumerated patents provides tubular graft structures exhibiting enhanced radial tensile strength, as well as enhanced axial tear strength, these structures all result in tubes exhibiting lower porosity. More specifically, the multi-layered ePTFE tubular structures of the prior art exhibit a smaller microporous structure overall, especially at the inner surface, and accordingly, a reduction in the ability of the graft or
15 stent/graft composite to promote endothelization along the inner surface.

Another endoprosthesis commonly used for the treatment of diseases of various body vessels is a stent. A stent is a generally longitudinal tubular device formed of biocompatible material which is useful to open and support various lumens in the body. For example, stents may be used in the vascular system, urogenital tract and bile duct, as well as in a variety of
20 other applications in the body. Endovascular stents have become widely used for the treatment of stenosis, strictures, and aneurysms in various blood vessels. These devices are implanted within the vessel to open and/or reinforce collapsing or partially occluded sections of the vessel.

Stents are generally open ended and are radially expandable between a generally
25 unexpanded insertion diameter and an expanded implantation diameter which is greater than the unexpanded insertion diameter. Stents are often flexible in configuration, which allows them to be inserted through and conform to tortuous pathways in the blood vessels. The stent